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Structural Behavior of Concrete Flange Continuous Deep Beams with Carbon Fiber Reinforced Polymer (CFRP)

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Abstract
The load capacity and behavior of a reinforcement concrete deep beam at each loading stage based on the geometric property of the section, steel arrangement, load and support condition. The current study used to inspect the structural response of continuous reinforcement concrete deep T-beams reinforced with the carbon fiber reinforced polymer (CFRP) failed in shear. The study analyzed three concrete deep T- beams, these beams contain CFRP reinforcement and three concrete deep T- beams, these beams contain steel reinforcement for comparison. The deflection, failure mode, crack pattern also studied at analysis. the shear failure is predominant for all analysis T-beams. And the result shows when keeping the rate of the CFRP reinforcement constant and increasing a/d ratio substantially affects the shear strength and the collapse loads decreasing, also the CFRP reinforced T-beams can be showed the shear strength value higher than those of similar steel reinforced T-beams.

1. Introduction
when span/depth between 2.0 to 2.5, the reinforcement concrete beams are classified as deep beams, the stress of deep beams distribution with depth is nonlinear even at the elastic stage, the resistance of deep T-beam is usually leaded by shear rather than flexure and shear strength is a function of many factors such as the compressive resistance of concrete, major and web reinforced, slenderness, load and supporting condition [1]. Khudair studied the structural response of reinforcement concrete flanged continuous deep beams failing in shear by testing twenty-one samples and compared the results with three-dimensional non-linear finite element analysis. The study concluded that the nonlinear three-dimensional finite element model is capable of predicting the behavior of the flanged continuous deep beams with a good accuracy [2]. Lubell and Garay have tested six beams with depth/span equal to 2, the campaign of experimental is conducted to Investigate the response of large-scale deep reinforcement concrete beams consist of high longitudinal steel strength. The conclusion appears that the beam capacity decreases when the shear span/depth ratio increase, and when the longitudinal steel ratio decrease [3]. Ajel 2011 study responds nine concrete deep beams rectangular section reinforcement by the carbon fiber reinforced polymer (CFRP), the influence of the shear span to effective depth ratio, a/d, and the CFRP main reinforcement ratio, ρ, on the shear response of CFRP reinforced concrete deep beam was inspect. It was shown that with increasing the CFRP reinforced ratio in the range of (0.402%-0.805%), the collapse loads increasing about (6.5%-72.84%) and the crack width in CFRP reinforcement deep beams was wider by (38.9%-55.1%) compared with steel reinforced beams [4]. The aim of study investigates the structural response of deep reinforcement concrete flange beams (T-Beam), which reinforcement by carbon fiber reinforced polymer bars (CFRP) and failed in shear.

2. Finite Element Modeling
2.1. Modeling of Concrete
Three-dimensional brick element (Concrete 65) is using for the modeling of concrete without or with reinforced bars; this element is able to represent the crack in tension and crush in compression. This element was defined by 8-nodes, these nodes have three degrees of freedom: translation of the node in x, y, and z-direction Figure 1[5].

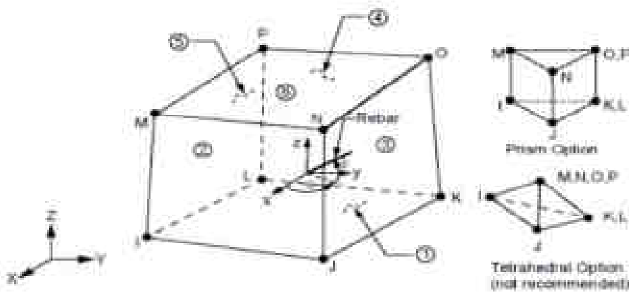

Figure 41; Concrete 65 Geometry, (ANSYS 17.2).

2.2. Modeling of Reinforcement

CFRP and steel reinforced bar are signified by using two nodes separate representation (LINK8). The 3-dimension spar elements are a uniaxial compression- tension elements with 3-degree of freedom at each node. The geometry, node locations, and the coordinate system for this element are shown in Figure. 2. [5].

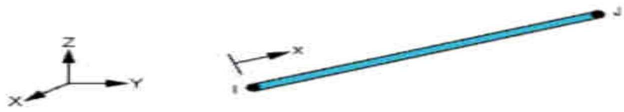

Figure 2 Link8 Geometry, (ANSYS, 2007).

2.3. Geometry

Three concrete flanges deep beam with carbon fiber reinforced polymer reinforcement (CFRP) and three concrete flange beam reinforced by steel for comparison are analysis by used ANSYS program shown in figure 3.

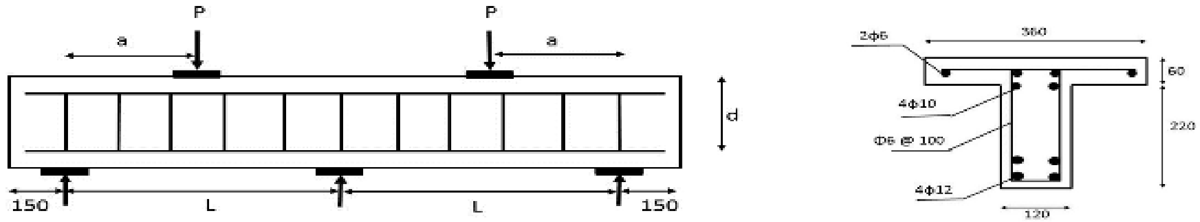

Figure 3 Section and Beam dimension

The beams are set in three groups as shown in Table 1, the group of steel reinforced represent by symbol RC and the carbon fiber reinforced represent by CFRP. Three type of shear span to depth (a/d) ratio were applying on the experiment beams (1.0, 1.25, and 1.5) and concentrated loads were placed at mid-span of the beam.

Table 1 Beam Properties

Group	a/d	Symbol	Fc (MPa)	Tension Bars (mm)	d mm	Compression Bars (mm)	L mm	As type
1	1	RC 1	32.3	4 φ 10	250	4 φ 10	500	steel
		CFRP1		4 φ 10	250	4 φ 10	500	CFRP
2	1.25	RC2	32.3	4 φ 10	250	4 φ 10	750	steel
		CFRP2		4 φ 10	250	4 φ 10	750	CFRP
3	1.5	RC3	32.3	4 φ 10	250	4 φ 10	1000	steel
		CFRP3		4 φ 10	250	4 φ 10	1000	CFRP

3. Material Properties

3.1. Concrete Behavior

Development of the new model for study the response of concrete is a challenging task. The concrete material is a quasi-brittle and the response in tension and compression is very different. The concrete is characterized by tensile stress about 8-15% of the compressive stress. The normal concrete has a stress-strain curve as shown in Figure 4. In compression, initially the linear elastic relation between stress-strain for concrete up to about 30 % of maximum compression stress. After that, the relation increases nonlinearly to point that compressive stress is maximum. When the stress-strain curve reaches to maximum value σ_{cu} then it starts to slide downwards into softening range, and the concrete begins failure in the crush at ultimate strain ε_{cu}. In tension, the linear elastic relation between stress-strain for concrete until reach maximum stress value. After that, the cracks begin to appear in the concrete and the stress decreases to the zero [6-7-8]].

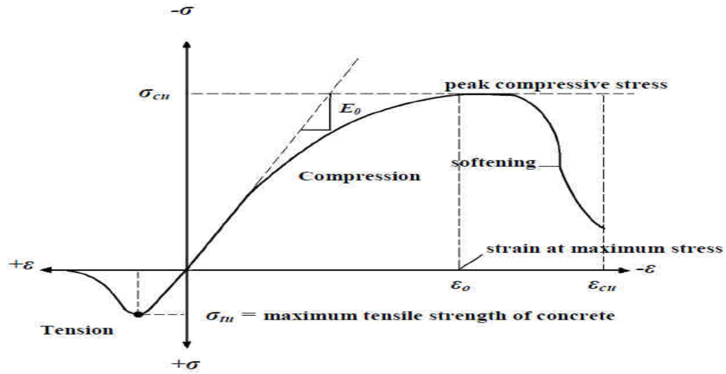

Figure 4 Stress-Strain Curve for Concrete.

The program (ANSYS) is required the relation of uniaxial compression stress-strain for concrete (Figure 4). in this study, equations 1, 2 and 3 used to represent the uniaxial compressive stress-strain response for concrete in Numerical expression. [9].

$$f = \frac{E_c\,\varepsilon}{1+\left(\frac{\varepsilon}{\varepsilon_o}\right)^2} \qquad ---------(1)$$

$$\varepsilon_o = \frac{2\,f_c'}{E_c} \qquad ---------(2)$$

$$E_c = \frac{f_c}{\varepsilon} \qquad ---------(3)$$

Where: f = Stress at any strainε.
ε = Strain at stressf.
ε_o = Strain at the ultimate compressive strength f_c'.

3.2 Steel bars and Steel Plates Behavior

the steel has bilinear curve idealization for uniaxial stress-strain relation, representing elastic-plastic response with strain hardening. This relationship is assumed to be similar, in compression and in tension as shown in Figure 5, and table 1 shows Physical Properties for Reinforcement Bars [10].

Table 2 Physical Property for Reinforcement Bars.

Tensile strength	Ultimate strength	Modulus of Elasticity	Ultimate strain
MPa	MPa	GPa	%
440	621	200	18.20

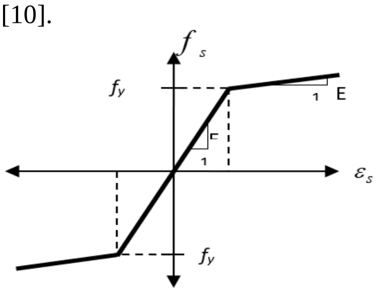

Figure 5 Stress-strain relationships for steel.

3.3. CFRP Bars behavior

The behavior of carbon fiber reinforced polymers (CFRP) bars used in the present study is assumed to have linearly elastic stress-strain relationship up to failure and does not exhibit any plastic behavior before the rupture as shown in Figure 6. Failure in carbon fiber reinforced polymers CFRP bars is reached when the strain (ε_{pu}) corresponding to the rupture stress (f_{pu}) is reached. Table 3 shows Physical Properties for CFRP Bars [11].

Table 3 Physical Properties of CFRP Bar

Tensile strength	Tensile Modulus of Elasticity	Ultimate strain
MPa	GPa	%
1543	450	0.017

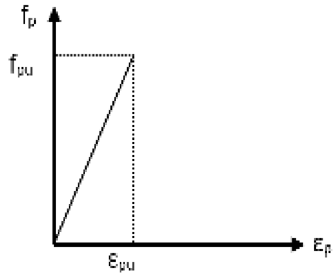

Figure 6 Stress-Strain Relationships for CFRP Bars

4. Results and Discussion

4.1. General Behavior

Generally, all the beams are failed by shear. The failure load and displacement are shown in the table (4), the load is compared with the experimental result for beams contain steel reinforced only [2], and the beams are contained CFRP analyzed by ANSYS program only. For beams with a/d ratio of 1.0, the first diagonal crack suddenly appeared in the middle-depth of the beams at the middle shear area between the applied load and the intermediate support, when the load increased, the inclined cracks are wider and extended through the flange. At failure load, two major inclined cracks were opened from the support to the applied load. For the beams with a/d ratio of 1.5 and 2.0, similar behavior was observed except that the formation of the inclined cracks was preceded by the development of a few fine flexural cracks at the bottom of the beam near the center of spans and at the top of the beam over the intermediate support. The mode of failure of all beams was characterized by opening of only one major inclined cracks extending between the load and the intermediate support. The displacement value at mid-span can be considered as a measure of ductility with an increased ratio of a / d.

Table 4 Comparisons between experimental load and finite element load.

Beam	Experimental failure load Kn Pu_{Exp}	Numerical failure load Kn Pu_{FE}	$\frac{Pu_{FE}}{Pu_{Exp}}$	Experimental failure Deflection mm	Numerical failure Deflection mm
RC 1	384	360	0.94	0.64	0.52
CFRP1	---------	410	---------	---------	0.936
RC 1.5	260	252	0.97	1.22	0.97
CFRP 1.5	----------	271	---------	---------	1.412
RC 2	241	243	1.01	2.26	1.92
CFRP 2	---------	246	---------	---------	2. 486

4.2. Load-Deflection curve

The deflection was measured at the middle of the span and at the center of the bottom face of T-beam for the numerical analysis and experimental. Figure 7 observe the load-displacement curve by used finite element analyses for steel reinforcement T-beams and CFRP reinforcement T-beams, the steel reinforced beams compare with the experimental data, the finite element analysis agrees well with the experimental result for the steel reinforcement beams. In the linear limits, the carried load-deflection curves from the finite element analysis are stiffer from the test data .

Despite the relative dowel effect contribution of the CFRP main reinforced but the shear stress for CFRP reinforced deep T-beams ware more than the steel reinforcement deep T-beams. This can be referred to the high tensile stress of CFRP main reinforcement, which makes equilibrium with the softer contribution of other shear strength mechanisms. However, the vertical displacement of steel reinforcement T-beams is less than that CFRP reinforcement T-beams.

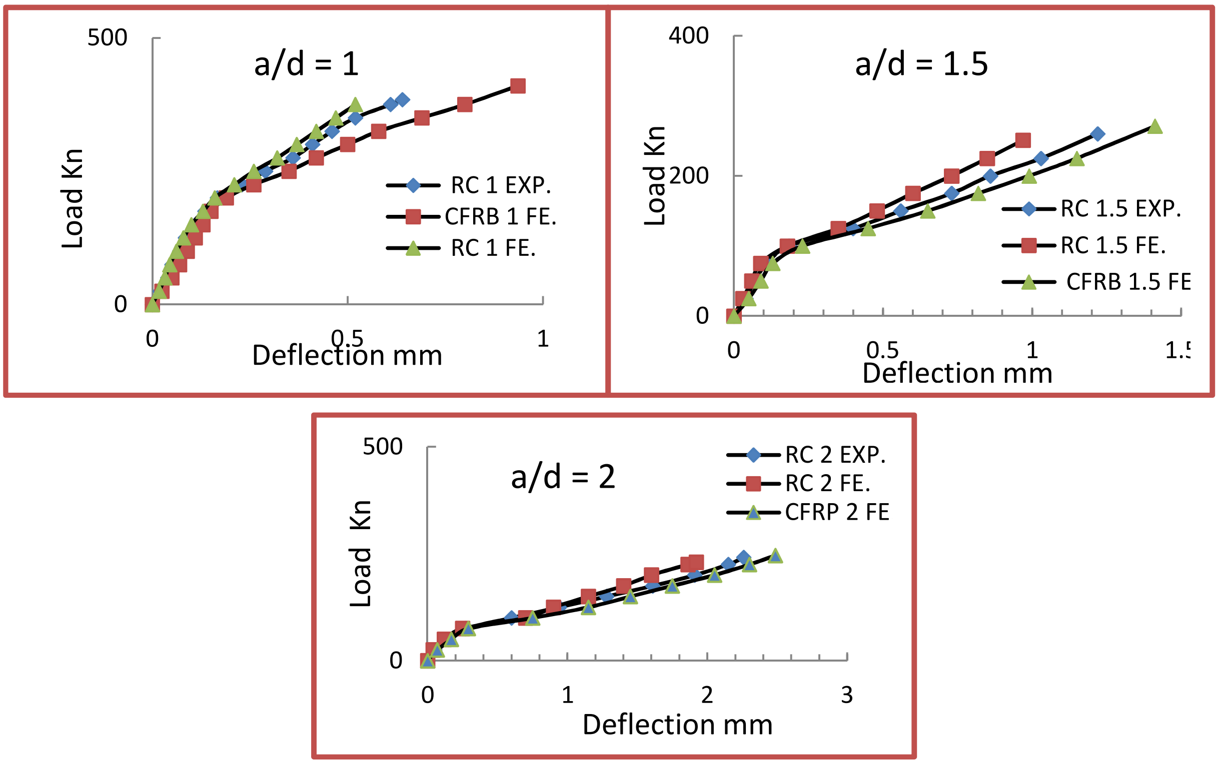

Figure 7, Load deflection curve at mid-span for beams

4.2. Effect of Shear Span to Depth Ratio, a/d

The inclined cracking and subsequent failure of deep reinforcement concrete T-beam are strongly affected by shearing stress and flexural stress, this effect may be considered as a function of a/d ratio figure 8.

The result shows that the effective span of shear to depth ratio (a/ d), has an important effect on the capacity of deep concrete T-beams with CFRP reinforced. For deep T-beams reinforced with CFRP bars, the increasing of a/d from 1 .0 to 1.5 leads to decreased the shear strength with an average about (51.3 %), and decreased about 66.6% when a/d increasing for 1. 0to 2.0. The reduction in shear stress is significantly due to the decline in the angle between the tension tie and diagonal compressive support, which led to decrease in the influence arch action mechanism.

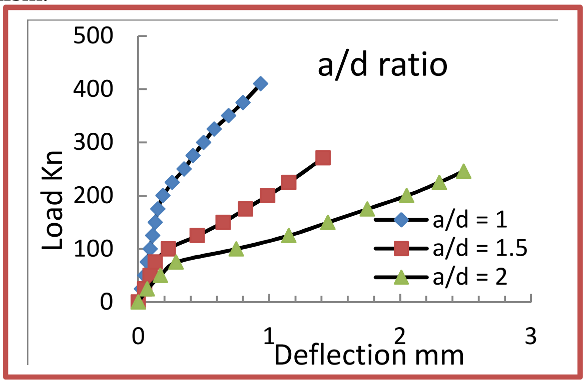

Figure 8 Load deflection curve for different a/d

4.3. Cracking Pattern

The predicated cracks pattern for T-beams under failure loading are shown in Figures (9 -14). For beams RC1, RC1.5, CFRP1 and CFRP 1.5, the first inclined crack was formed around the line that joint the edge of loading plate and an edge of an interior support plate. With increasing the applied load more cracks have appeared in both interior and exterior shear span. In these beams, vertical cracks were formed at mid-span at bottom of the beams. In the beams, CR2 and CFRP2 the vertical cracks also formed but at top of the beams near the interior support.

5. Conclusions.

1. The typical 3-dimensional finite element model used in the current study is capable to simulate the steel and CFRP reinforced concrete deep beams. The patterns of Crack and ultimate load surmised are very close to those measured through the experimental data for steel reinforced beams.
2. Using tensile reinforcement bars from CFRP in RC deep T-beam had an important effect on the shear stress and vertical displacement of analyzed T-beams. The high elastic modulus of CFRP rebar is used as a critical factor in increasing the vertical displacement of reinforcement concrete deep beams
3. From analyzing deep T-beams, It can be observed that keeping the amount of the main CFRP reinforcement constant and increasing a/d ratio substantially affects the shear strength, also the collapse loads decreasing about (51.3%-66.6%) by the increase in a/d ratio from (1-2).
4. It is shown that the patterns of Crack in CFRP reinforcement deep T-beam is different from that in the same beam contain steel reinforced in terms of crack size because of the high elastic modulus of CFRP bar, while it is similar in term of crack propagation, length, and orientation.
5. Finally, the CFRP reinforcement T-beam can be obtained by shear stress value high than those of similar steel reinforcement T-beam about (6%-9%). because the mechanical advance of arch action due to the tensile stress of steel bar is very small than that of CFRP.

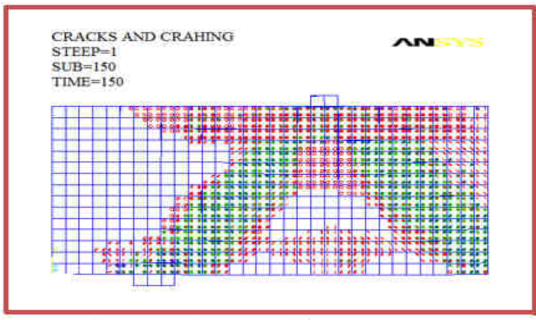

Fig 9 Crack Pattern for RC 1

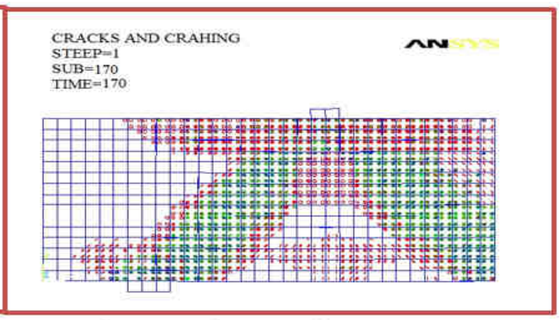

Fig 10 Crack Pattern for CFRP 1

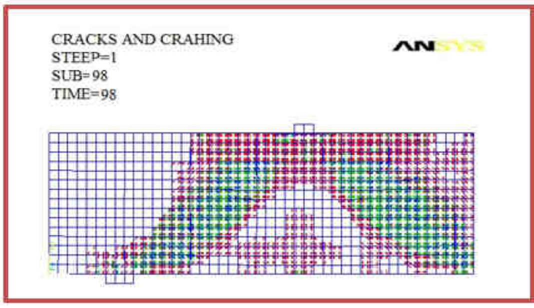

Fig 11 Crack Pattern for RC 1.5

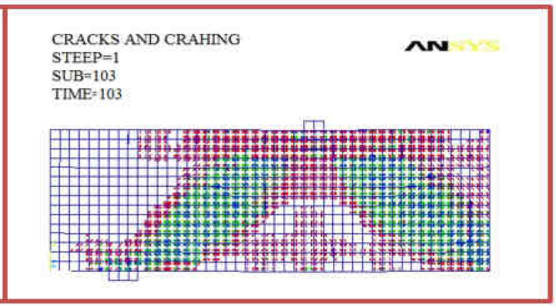

Fig 12 Crack Pattern for CFRP 1.5

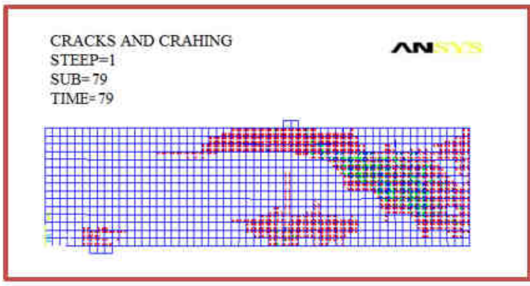

Fig 13 Crack Pattern for RC 2

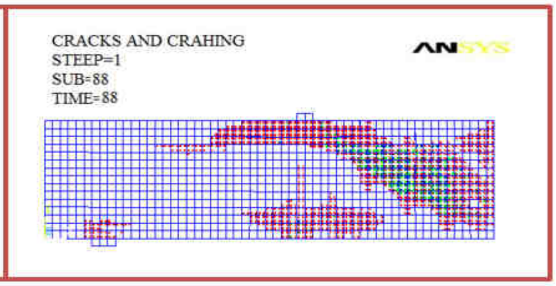

Fig 14 Crack Pattern for CFRP 2

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